ATD Report T-65-34 28 May 1965

Translations of Soviet-Bloc Scientific and Technical Literature

SOME SPECIAL FEATURES OF THE COMBUSTION OF LIQUID-FUEL DROPLETS

Translation

Aerospace Technology Division
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FOREWORD

This translation has been prepared in response to a special AFSC request. The article was originally published as follows:

Fedoseyev, V. A., D. I. Polishchuk. Nekotoryye osobennosti goreniya kapli zhidkogo topliva. Trudy Odesskogo gosuniversiteta im. I. I. Mechnikova. Voprosy gazovoy dinamiki, ispareniya i goreniya v dispersnom vide, v. 152, Seriya fizicheskikh nauk, no-8, 1962.

SOME SPECIAL FEATURES OF THE COMBUSTION OF LIQUID-FUEL DROPLETS

The investigation of liquid droplet combustion is very important for the theory of evaporation and combustion of dispersed fuel and for the practical application of aerosol burning. Up to the present time the problems of burning of particles surrounded by other particles have not been sufficiently studied. These problems have recently been investigated at the Combustion Physics Laboratory of the Odessa State University under the general supervision of Docent V. A. Fedoseyev.

The aerosol droplets are small. Experimental investigation of the evaporation and burning of these droplets involves difficulties connected with the experimental procedure. This problem is mainly caused by the small size (a few microns) of the droplets, which cannot be suspended from a device and investigated through a microscope. Furthermore, the droplets remain in the field of vision for a very short time, in which the measurments must be made.

V. A. Fedoseyev [1] suggested the application of his method of traces to the study of the evaporation and burning of small droplets moving with the airstream. The original method has been elaborated for the study of burning metal particles. The kinetics of the evaporation of individual water aerosol droplets, the burning of liquid fuel droplets, and the burning of metal particles in aerosols have been investigated by the same method.

The method of traces is a combination of the method of recording traces of evaporating or burning droplets in motion on a photographic plate and the method of obtaining kinetic data on the evaporation

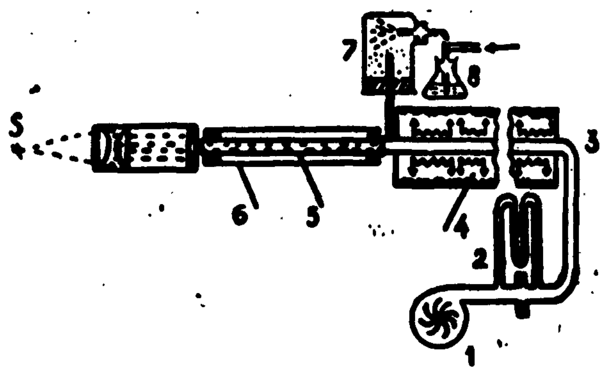

Fig. 1

(burning) based on the measurement of the total evaporation or burning time (lifetime) of particles of various sizes. In the experiments the lifetime (τ) of droplets of different masses (m) were determined, and a graph of the dependence of τ on m was established. From the graph, a plot of droplet mass vs time was obtained. Assuming that the droplets are spherical, the variation of the surface and diameter of the droplet during evaporation or combusiton can be calculated. The experimental installation used for the tests is shown in Fig. 1.

The air stream in the porcelain pipe (1), is maintained by a blower. A rheometer (2) with a water manometer measures the air stream velocity. The porcelain pipe passes through several tubular electrical furnaces (4), which can heat the air stream from room temperature up to 1200°C. The air heated to the required temperature passes to the glass pipe (5), which is placed in another transparent glass pipe (6) in order to prevent cooling. A beam of light parallel to the pipe (5) is provided. The width of the beam is so adjusted that it does not light the walls of the pipe. An OI-18 luminescent light source with an SVD-120A lamp was used.

The aerosol is produced by an atomizer (8) in a small chamber (7), from which it travels through a vertical pipe into the pipe (5) where it mixes with the hot air. The small droplets, a few microns in diameter, are carried away by the stream of air, becoming stationary relative to the stream. When the light source is turned on, the lighted droplets appear as small stars. The motion of the illuminated droplets moving with the stream in the pipe (5) is recorded on the photographic plate as a trace, whose length depends on the evaporation rate of the droplet and on the flow velocity in the pipe (5). If conditions in the pipe cause droplets to evaporate quickly (very hot dry air), the trace generated by the droplet is short. Knowing the air velocity in the pipe (5) and the length of the trace, the evaporation time of the droplet may be calculated. With other conditions equal, i. e., at identical velocities, temperatures, and humidity of the air stream, the length of the traces is determined by the droplet dimensions: the larger the droplets the longer the traces.

It is possible to determine the dependence of the lifetime of droplets on their masses by injecting droplets of various masses into the stream. It has been established in this way that in the case of water droplets of a few microns, Sreznevskiy's law is satisfied.

Instead of one droplet, an aerosol, i.e., a system characterized by a given distribution of droplet sizes, may be introduced. In an ideal case, an aerosol containing droplets of identical size should be used. In that case, no individual traces but a continuous luminous area should be visible. The length of this area is determined by the evaporation rate of the droplets in the aerosol. With other conditons equal, the length of this luminous area depends on the mass of droplets in the aerosol. The lifetime of a droplet in a space filled with other droplets may be calculated according to the length of the luminous area and the air stream velocity. By changing the droplet dimensions, it is possible to determine the dependence of the dependence of the lifetime of a droplet in an aerosol on its mass.

The production of monodispersed mists and aerosols, however, presents a very difficult problem, especially in the case of aerosols containing liquid droplets. It is known that in the study

of metal-particle combustion a given particle size can be selected with the help of sieves or by gravitational sedimentation in a long pipe. In the second case, particles of given dimensinns will reach the bottom at a given time. The selection of liquid particles is much more difficult.

In our experiments the aerosol was contained in a horizontal glass pipe, into which steam from a boiler and a stream of cool air were injected. Experiments indicate that the aerosol produced under these conditions may be considered as monodispersed. Therefore, the boundaries of the aerosol in the pipe were sufficiently well defined. The OI-18 light source generates a narrow beam of rays parallel to the axis of the pipe (5). The pipe observed from the side is dark when the aerosol is absent. When it is introduced, a glow is observed, from which it is easy to determine the evaporation limit of a given aerosol. For the calculation of the evaporation rate the dimensions of the droplets must be known. These dimensions were determined by the interception of droplets on vaseline-oil layer on a microscope slide and measured in an MP-3 microscope with an ocular grid. In the preparation of the vaseline-oil layer, measures were taken to avoid the effect of the resorption of small droplets. The curve of aerosol droplet distribution according to size is shown in Fig. 2. The diagram shows that the curve has a well defined maximum: the average droplet size was 8 microns, and the number of droplets only half as large (4 microns) did not exceed 7 to 8%.

An aerosol with such a droplet distribution has been used for determining the influence of temperature on the evaporation rate, specifically the dependence of droplet lifetime on the stream velocity at temperatures varying from room temperature to 120°C. The graph of this dependence is shown in Fig. 3. When the temperature is increased, the length of the area occupied by the aerosol and droplet lifetime diminish. This dependence has the same character as in the evaporation of large droplets. For comparison, it is interesting to consider the curve of the dependence of lifetime on temperature for a drop of water 2 mm in diameter calculated according to data of previous investigation [2]. Fig. 4 shows such a curve for the evaporation of a drop of water in a stream flowing with a velocity of 0.5 m/sec.

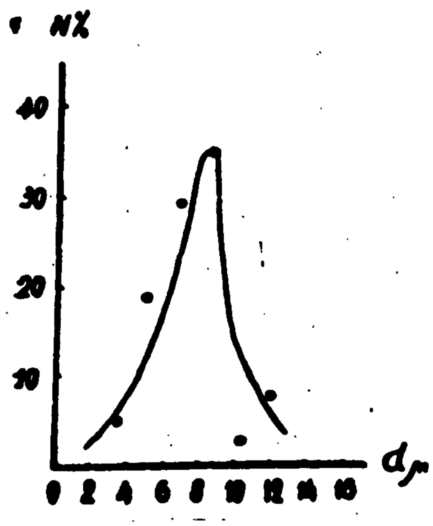

Fig. 2

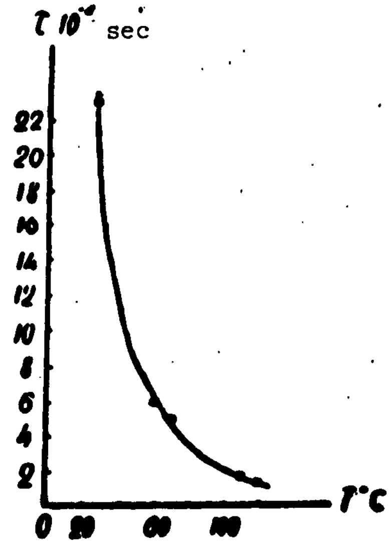

Fig. 3

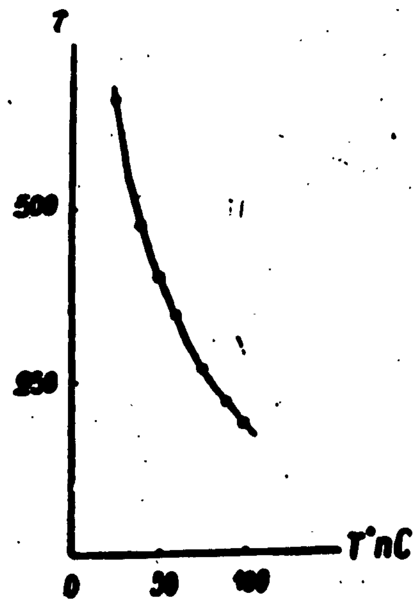

Fig. 4

Comparison of these curves demonstrates that the effect of the temperature on the evaporation of small droplets (a few microns in diameter) remains qualitatively the same as in large-droplet evaporation.

The burning of small droplets of liquid fuel also was experimentally investigated with the apparatus described above. The investigation met with additional difficulties because the method of droplet generation which is used in the evaporation of water droplets cannot be applied to gasoline or other liquid fuels, because of the possible ignition of the corresponding aerosol, flame propagation into the container where atomization takes place, and explosion of the container. It was necessary, therefore, to give up the investigation of droplets of the usual liquid fuels. On the suggestion of G. A. Varshavskiy, materials which are solid at normal temperatures were used. These materials may be ground into fine powders and then separated into fractions of various sizes. Injected into a stream of hot air, these particles change quickly into liquid droplets and ignite. Thus the problem is reduced to the burning of liquid droplets.

For this purpose tar, paraffin, naphthalene, colophony, celluloid, plexiglass and other similar materials may be used. We experimented with particle-droplets of plexiglass and celluloid, and G. A. Varshavskiy and L. G. Peshchanskaya, with droplets of paraffin. Naphthalene and colophony were not used because of the resulting heavy deposit of soot on the pipe walls.

We experimented with burning single, small particle-droplets of plexiglass and with burning aerosols of these particles. When the number of burning particles in a unit volume is increased, the number of traces increases. It has been established that individual traces are visible as long as the number of particles is small. There is, however, a minimum number of particles; when this is exceeded one particle combines with the flames of particles nearby, and a continuous flame is formed. The formation of the continuous flame is accompanied by a sharp temperature rise and consequently by increased radiation.

Further increase in the number of particles in a unit volume leads to a point when the temperature and radiation stop increasing. The curves of temperature and radiation increase have the character of saturation curves. This state is shown in Fig. 5, which gives the dependence of the flame temperature on the number of particles per unit volume in burning aerosols in a stream of air heated to 1000°C and flowing at a velocity of 6^{m}/sec.

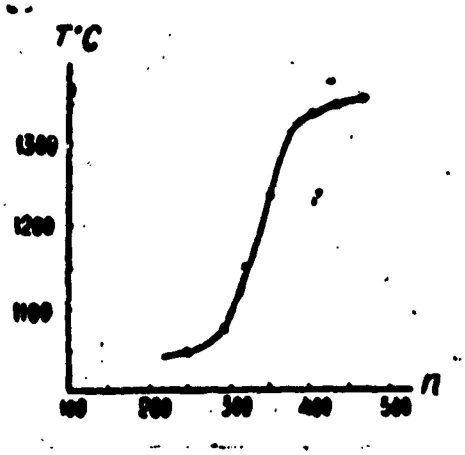

Fig. 5

The length of the continuous flame depends on the droplet size. Experiments show that some differences in droplet size are indicated mainly by the different distances at which combustion is completed. The sharply outlined initial flame boundary indicates that the time intervals of preflame heating are identical for all particles. (A conical flame indicates that no measures were taken to obtain a П-shaped velocity profile.) Figs. 6, 7, 8 and 9 show photos of flames formed during the combustion of an aerosol of plexiglass particles.

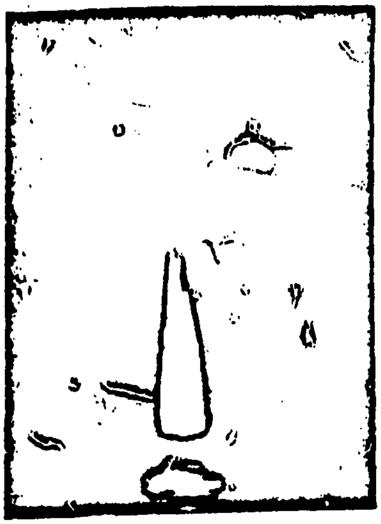

Fig. 7

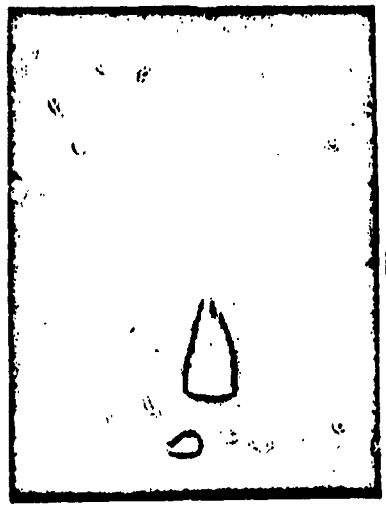

Fig. 9

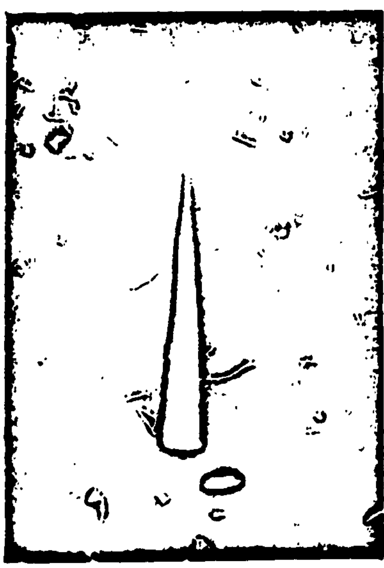

Fig. 6

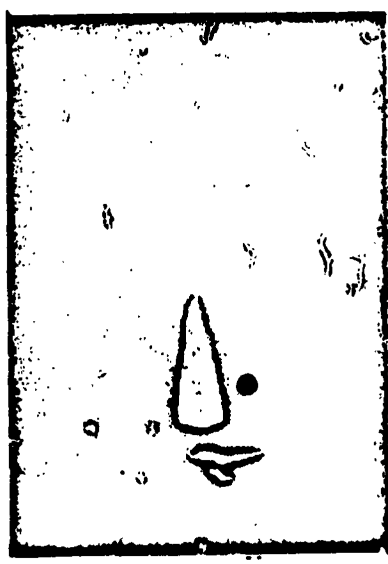

Fig. 8

On the basis of the flame length of various fractions, data on the variation of particle sizes in the burning process were calculated, i.e., data on the variation of droplet diameter as a function of burning time. From these data the variation of the surface area of the droplet with time was calculated. This dependence is represented in Fig. 10. The sharp deviation from the linear law in droplet combustion under conditions of a continuous flame, i.e., when the droplet is surrounded by other burning droplets, may apparently be explained by the fact that in this process the droplet acquires the major amount of heat by radiation, specifically by radiation from the surrounding particles. It has been demonstrated in one of our former investigations that this fact is connected with the deviation from the linear law of the surface variation with time. It is also possible that the plexiglass particles do not change to liquid droplets instantly but that they are ignited at one place, after which the flame propagates gradually over the entire surface.

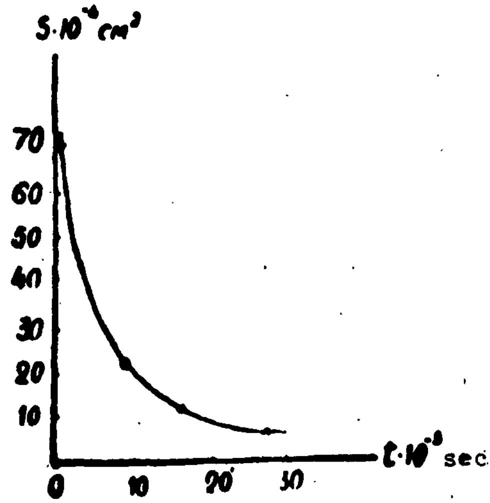

Fig. 10

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2. Fedoseyev, V. A., Polishchuk, D. I., Zhurnal tekhnicheskoy fiziki, v. 23, no. 2, p. 233, 1953.

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